Estimation of Vertical Distributions of Water Vapor and Aerosols from Spaceborne Observations of Scattered Sunlight

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LONG-TERM GOALS

The scientific aims of this project are to investigate, develop, and apply methods based solidly on scattering physics and inverse theory to estimate vertical distributions of water vapor and aerosol properties from hyperspectral observations of scattered sunlight. We seek especially to advance methods for the lower troposphere, where water vapor and aerosols are concentrated and affect naval systems most strongly. We are working on (distinct) methods applicable over the ocean and over coast land.

OBJECTIVES

Our immediate objectives are: (1) to quantify the invertibility of hyperspectral (e.g., NEMO/COIS) data over land for water vapor profile information, based on the temperature (and therefore altitude) dependence of water vapor absorption lines, and to test inversion schemes using existing (airborne) data as warranted; and (2) to develop a method to estimate lower tropospheric water vapor profile parameters over the ocean based on hyperspectral observation and clear-air aerosol scattering.

APPROACH

Both of these inversion problems can be cast (approximately) as linear inverse problems. In the case of the sensing over land, the form of the problem is not that of any classical mathematical transform, so regularization, singular value decomposition, and Backus-Gilbert techniques are the methods of choice (see below). In the case of sensing over the ocean, the problem can be cast (approximately) as the inversion of a Laplace transformation. For this case, we are developing a new mathematical method for inversion when the data are sparse but subject to choice (for example, in wavelength). This approach should result in an inversion procedure more powerful (for this specific problem) than the general methods for linear inverse problems.

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WORK COMPLETED

This program shifted focus upon consultation with program management in late June of 1999. Since that date, we have acquired, implemented, and applied MODTRAN to characterize the temperature dependence of absorption due to water vapor. Over land, sunlight scattered by the ground effectively provides a source. In cases where knowledge of the variation of temperature with altitude exists or can be presumed (e.g., a lapse rate prediction from a numerical weather model), this temperature dependence can, in principle, provide the physical basis for estimation of the vertical profile of water vapor concentration.

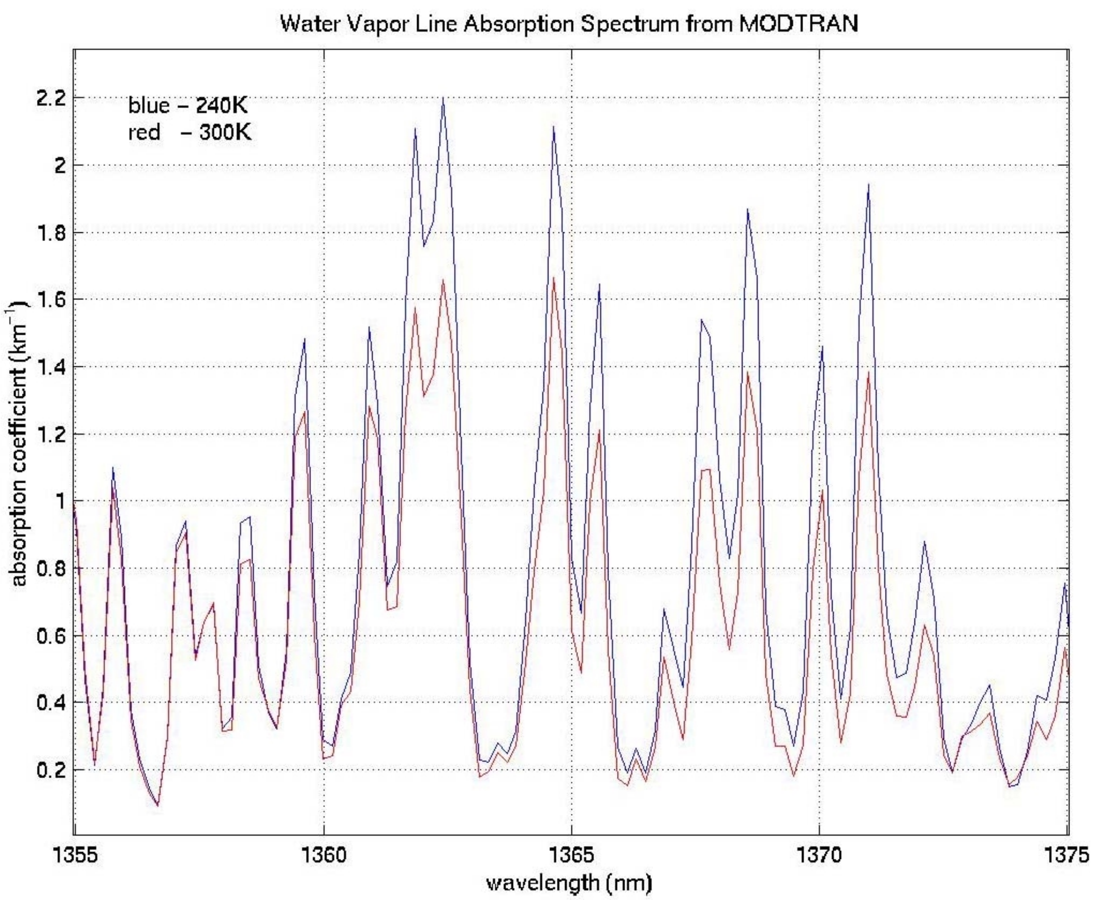

Figure 1 illustrates the temperature dependence of absorption due (solely) to water vapor lines, as a function of wavelength near 1360 nm.

To investigate the practical feasibility of the over-land approach, we have compared inversion methods based on regularization, singular value decomposition [Varah, 1983], and Backus-Gilbert techniques [Parker, 1994]. Results are discussed below.

Over water, we have formulated the problem in terms of an approximation to radiative transfer which shows that clear-air data are, essentially, a Laplace transformation of the desired information.

RESULTS

Regularization methods all require what are, in the end, subjective choices of conditions to impose on the retrieval and the degree to which those conditions are enforced (coded by the regularization parameter). By using the Laplace transformation as an example, it becomes apparent that, unless there is strong a priori knowledge to indicate precise choices, regularization can do no better than to restrict retrievals to the obvious ranges (technically, sub-spaces) indicated by the geometrical mapping properties of the transformation that yields the observations (from the profile we want to estimate). A cleaner and less subjective tool for that latter task is singular value decomposition (SVD), which provides a direct indication of the number of independent pieces of information in a given data set, as well as the sensititivies of the retrieval. We have therefore based our retrieval algorithm development partly on SVD.

We do so only in part, however, because SVD only obliquely addresses another key question: What is the range of (pressure) altitudes over which we might expect retrievals of a given fidelity, given a prescribed set of data. To address this question, we are developing a variant of Backus-Gilbert theory. This theory is usually used to address questions of resolution in the retrieval, but can as well indicate regions of the retrieval range which are poorly determined by the data.

Preliminary results indicate that water vapor profile inversion over land will remain difficult at best, even with data of the quality expected from the NEMO/COIS sensor. We are presently working to solidify and quantify this conclusion, as well as to specify the data characteristics that would facilitate profiling. We will present this work on a poster at the Fall Meeting of the American Geophysical Union in December, 1999.

IMPACT/APPLICATIONS

Advances in this work impact several fields in addition to that of naval sensor performance modeling: linear inversion theory (via advances in mathematics and methods), air-land and air-sea interaction (by providing new probing methods and information for near-surface fluxes), and boundary-layer meteorology (by improving understanding of lower boundary conditions and radiative and latent heat fluxes).

TRANSITIONS

Transitions from this work to related efforts have not yet been made.

RELATED PROJECTS

Water vapor estimation methods developed in this work will be adapted to related problems in other geophysical settings.

REFERENCES

Parker, R.L., Geophysical Inverse Theory, Princeton University Press, Princeton, NJ, 1994.

Varah, J.M., "Pitfalls in the numerical solution of linear ill-posed problems", SIAM J. Sci. Stat. Comput. 4(2), pp. 164-176, 1983.

PUBLICATIONS

Winebrenner, D.P. and J. Sylvester, "On the Invertibility of Near-Infrared Hyperspectral Ground Reflectance Observations for Lower-Tropospheric Water Vapor Profiles", To be presented at the Fall Meeting of the American Geophysical Union December 1999.